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Oral Perception Of Liquid Volume Changes With Age

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Abstract

Bolus volume has been widely studied, and research has demonstrated a variety of physiological impacts on swallowing and swallowing disorders. Oral perception of bolus volume has not, to our knowledge, been investigated in association with normal ageing processes. Research suggests many sensory changes with age, some within the oral cavity, and changes in swallowing function with age have been defined. The role of perception in oropharyngeal deglutition with age requires further investigation. The purpose of this study was to establish the psychophysical relationship between liquid volume and oral perception and examine changes with age. Healthy young and older adults were prospectively assessed using a magnitude estimation task differentiating five volumes of water deliveredrandomly to the oral cavity. Results suggest a fourfold increase in liquid volume is required by older participants to perceive an approximate twofold increase in the perception of volume compared with younger healthy adults. Sensory receptors in the oral cavity provide a feedback loop that modulates the swallowing motor response so that it is optimal for the size and consistency of the bolus. Changes in perception of bolus volume with age are consistent with other perceptual changes and may provide valuable information regarding sensorineural rehabilitation strategies in the future.

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Background

Research has firmly established that sensory input to the oropharyngeal mechanism impacts deglutition, and therefore, characteristics of a bolus, such as taste (1, 2), volume (3, 4), viscosity (5, 6) and temperature (7), affect swallowing physiology. Individual results from studies show variability, but refinement of questions asked and methods employed edge science closer and closer to a more clear understanding of these factors.

The impact of bolus volume has been reported, perhaps, more than any other variable. This is, in part, because bolus volume is manipulated during most investigations where swallowing data are collected, allowing it to be a consistent secondary question if not a primary one. Bolus volume has been shown to impact not only the more obvious factors such as lingual shape and pressure for holding and transfer, but also the timing of oral and pharyngeal reconfiguration and the magnitude of pharyngeal pressures (8, 9). An impact of bolus volume has been reported on laryngeal closure duration (10), duration of opening of the upper oesophageal sphincter, duration of velopharyngeal closure (11), tongue base pressure (11), total swallowing duration (11) and hyoid and laryngeal elevation (12), even though velocity may be affected more than distance for the hyoid (8). And these are just a few of the more recent reports on bolus volume, which span the last several decades.

The role that sensory input and perception of bolus volume plays in deglutition is not as well understood. Adjusting the amount of sensory input to the oral cavity has been demonstrated to impact swallowing.

Oral anaesthesia slowed swallowing speed (volume s^{-1}) and increased interswallow intervals in healthy young adults (13). In another study, anaesthesia delayed the onset of the pharyngeal swallow (14), which could increase the risk of penetration/aspiration. Decreased sensory input could, potentially, alter perception of bolus volume, but this has not been investigated. As many aspects of sensation diminish with age, the ageing process itself could impact bolus volume perception, as well. As silent aspiration has been reported to be volume dependent (15), and penetration/aspiration has been shown to occur more frequently in the elderly, even when examining healthy individuals (16), the question of bolus volume, perception of sensory input and physiological impact seems salient.

Currently, it is not known to what degree volume variation can be consciously perceived or if the sensory changes associated with normal ageing affect the perception of bolus size in the oral cavity. This study examined the psychophysical relationship between liquid volume and the oral perception of volume to address the following questions: What is the psychophysical exponent for liquid volume perception in normal adults? Are there age-related changes in liquid volume perception? Are there gender-related changes in liquid volume perception?

The goal was to improve our understanding of liquid volume perception and the impact of age and gender.

Methods

Participants

Ten healthy young adults under the age of 50 and 11 healthy older adults over the age of 60 participated in the study. Mean age for the young adults group was 31 years old with a standard deviation of ±11·47. There were five females and five males in the young adult group. Mean age for the older group was 69 years with a standard deviation of ±6·9. There were three females and eight males in the older adult group. Participants had no prior history of swallowing difficulty or history of central nervous system disease, and none were taking medication that are known to affect swallowing. This was a prospective investigation that is part of a larger randomised controlled trial; therefore, the number of participants in each group was determined by an *a priori* power analysis for that study (G Power 3.1*).

Procedures

All procedures were approved by the respective Institutional Review Boards prior to initiation of the study. As part of the research procedure, participants were asked to individually take 1, 5, 10, 15 and 20 ml of water into their mouths and subjectively rank their volume. Participants were consented and trained in modulus-free magnitude estimation. Magnitude estimation is a psychophysical technique in which participants are asked to assign a number to each stimulus that indicates their perception of where each stimulus's intensity (in this case volume) falls on a continuum compared to previous stimuli presented. For example, if one water volume presented seems twice as large as another, a number twice as large as the other is assigned to it. Each participant was seated comfortably in a chair, blindfolded and presented with forty trials of room temperature water over four different sessions on separate days. Data were collected over four sessions because these data were collected as part of a larger investigation requiring multiple sessions. Each volume of 1, 5, 10, 15 and 20 ml was presented eight different times in a randomised order over the four sessions. The investigator trained each participant on how to rate liquid volume using modulus-free magnitude estimation. Participants were given dictated instructions to take the entire amount into their mouths, think about the amount of water in their mouth, spit it out and then immediately assign the volume a number from 10 to 99 based on the perceived volume. The use of 10–99 as a rating scale was adopted rather than 0–10 or 0–100 because psychophysical studies have shown that a 10–99 scale is less susceptible to bias than the other scales (17). We adopted this convention for our study. Ten means 'no volume' and 99 means 'maximum volume'. Participants were instructed that if they perceived the volume in their mouths to be half as large as the previous volume, then they would assign it a number half as large. They were allowed to hold the water in their mouths for up to 10 s. Participants were given three practice volumes of 5, 10 and 20 ml, always in

*Heinrich Heine University, Dusseldorf, Germany the same order, to practise the sequence of taking the water into their mouth, spitting it out and assigning a numerical value. The investigator did not assign magnitude estimation values to the practice trials or provide specific feedback about the correlation between the volume and the participants' rating.

Statistical analysis

An exponent for the psychophysical law of oral perception of liquid volume was calculated in three ways: (i) for each participant, (ii) for the younger and older groups separately and (iii) for all the participants combined (IBM SPSS Statistic V21[†]). Each assigned rating and the corresponding actual volume were transformed using the logarithmic function. Linear regression was then used to calculate one trendline for each participant. The slope of that trendline represents the psychophysical exponent for that participant.

Age and gender differences for oral perception of liquid volume were analysed using a 2 (age) × 2 (gender) analysis of variance (ANOVA) using the exponents for each participant.

Results

Results indicate that the exponent for oral perception of liquid volume in healthy adults of all ages is 0·59. This suggests that a fourfold increase in liquid volume is required to perceive an approximate twofold increase in the perception of volume (see Fig. 1). The exponents ranged from 0·39 for an older man to 0·74 for a younger man. Mean exponents by age and gender are provided in Table 1.

Age and oral perception of liquid volume

There was a significant main effect for age ($P < 0{\cdot}01$) for oral perception of liquid volume (see Fig. 2). Moreover, Cohen's effect size value ($d = 1{\cdot}68$) suggested a high significance. A Pearson product–moment correlation coefficient was computed to assess the relationship between years of age and exponent for oral perception of liquid volume. There was a moderate negative correlation between these two

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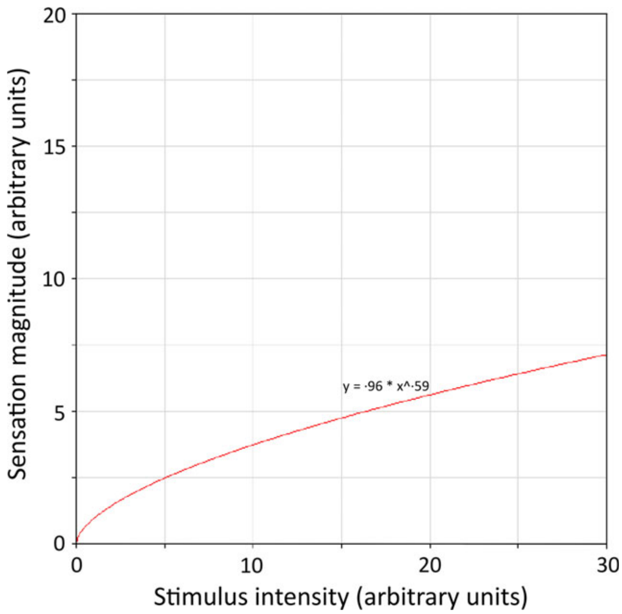

Fig. 1. Psychophysical power function for liquid volume perception plotted on linear coordinates.

Table 1. Mean (s.d.) exponents for oral perception of water volume by age and gender

Age	Men	Women	Group mean
Younger group	0·69 (0·03)	0·64 (0·04)	0·66 (0·04)
Older group	0·53 (0·12)	0·52 (0·04)	0·53 (0·11)

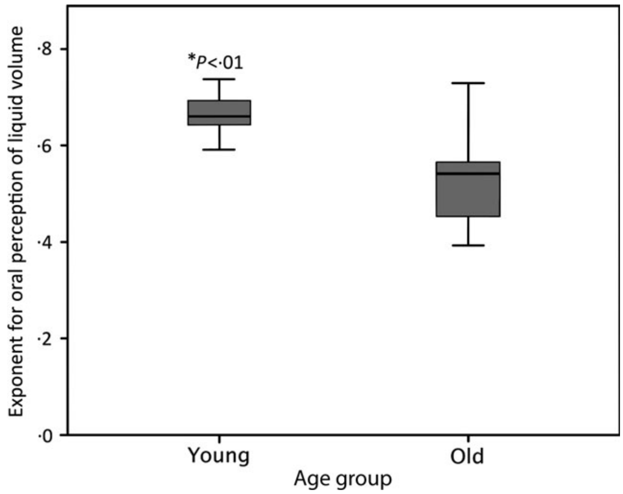

Fig. 2. Boxplot for exponent of oral perception of liquid bolus by age group. Data analysed by ANOVA demonstrated statistical significance between the two age groups ($P < 0{\cdot}003$).

variables ($r = -0{\cdot}603$, $P < 0{\cdot}01$). A scatterplot summarises the results (see Fig. 3).

Gender and oral perception of liquid volume

There were no main effects for gender and oral perception of liquid volume ($P = 0{\cdot}5$). Interaction between gender and age for oral perception of liquid volume was also not significant ($P = 0{\cdot}69$).

Discussion

Results of this investigation of perception of bolus volume with age are consistent with prior studies demonstrating other decreased oral sensations in the elderly, including proprioception, vibration, temperature and viscosity (18, 19). Exponents for volume reported in this study (0·59) are higher than those reported previously (20) for oral viscosity perception (0·33), but lower than those reported for other oropharyngeal sensory experiences such as taste of sweetness (1·3) and vocal effort (1·1) (20).

These results suggest that healthy older people have a higher threshold for perceiving changes in bolus volume (i.e. it takes a greater difference in volume amount to be perceived by older individuals). The standard deviation of the exponent is much larger in the older group (0·11 vs. 0·04), suggesting that although on average the older participants have reduced oral sensory perception, there is a wider range of ability in this group. Specifically, 2 of 11 in the older group had oral perception exponents that were well preserved and similar to those found in the younger group (0·68 and 0·73), as seen in Fig. 3. *Post hoc* analysis of screening measures did not reveal any particular factors about these participants that would illuminate the reason for their above average perceptual ability.

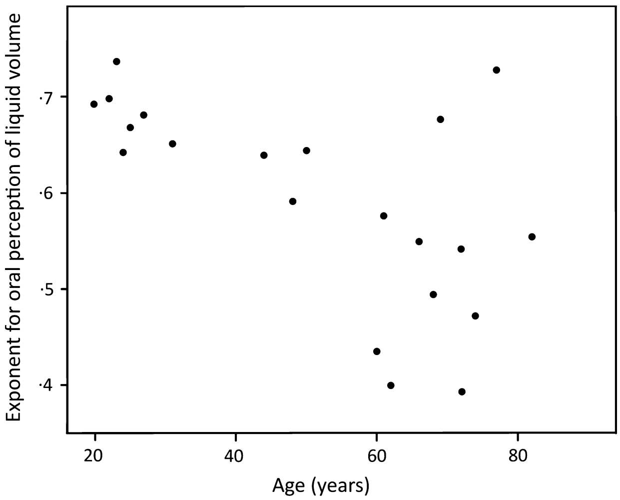

Fig. 3. Scatterplot of each participant's age and exponent demonstrates a moderate negative correlation ($r = -0{\cdot}60$, $P < 0{\cdot}01$).

Volume modification is a primary factor in dysphagia management. Limiting a patient's maximum volume per bolus likely does not impact their quality of life as severely as eliminating consistencies from their diet, as more severe modifications to diet are typically met with less compliance (21). However, such recommendations are sometimes made without training the patient to know what a 'small sip' or '5 ml swallow' feels like inside their mouth. The results of this study indicate that it may be difficult for elderly patients to discern appropriate small bolus size without external guidance, such as using a spoon or a special cup that limits liquid flow. In fact, this study demonstrates that older participants tend to underestimate the volume of larger boluses relative to younger participants, which could be a factor in the increased risk the elderly have for penetration/aspiration. However, it is not known whether perceiving volume changes is necessary for the physiological adaptations necessary to safely swallow larger volumes and this is an avenue for future research. Future research should investigate the correlation of oral sensory perception with swallowing function and whether oral perception can be rehabilitated in both the healthy elderly and in patient populations.

Sensory receptors in the oral cavity provide a feedback loop that can modulate the swallowing motor response so that it is optimal for the size and consistency of the bolus. Humbert and colleagues (12) investigated isolated pharyngeal swallows and complete oropharyngeal swallows and reported that without oral sensory input, the hyolaryngeal kinematics of swallowing gradually adapt over time to repeated exposures of a stimulus. With oral sensory input, this adaptation did not occur, indicating that oral sensation provides a stabilising framework for the pharyngeal swallow to occur. That investigation focused only on hyolaryngeal mechanics, and additional research would be needed to assess other aspects of the pharyngeal swallow. Nonetheless, accurate processing of oral sensory information would seem critical to the success of the oropharyngeal swallow.

Cortical activity increases with age, especially in the right hemisphere (21). Humbert and colleagues suggested this increase in activity demonstrated swallowing to be more challenging for older adults and, therefore, in need of more cortical recruitment. By the same token, younger individuals may be able to simply swallow more efficiently. Saliva swallows elicited more cortical activity than bolus swallows, lending more supporting evidence. Despite the increase in cortical activity associated with swallowing in the elderly, delays in swallow onset, penetration/aspiration on larger boluses (16) and increases in pharyngeal residue (22) are more common. Silent aspiration may be more likely, as well (15). Psychophysical perceptual acuity to bolus characteristics may or may not be required for swallowing modulation, but our results certainly suggest a possible correlation between the two. Prior research (23) has demonstrated with a similar magnitude estimation task in young healthy subjects that oral perception of bolus weight and volume conform to Fechners & Steven's psychophysical laws (20). With the current results indicating significant changes in the perception of bolus volume and an abundance of prior data suggesting swallowing declinations with age, additional research is warranted and should explore cortical activation associated with changes in bolus volume across the age span, as well as under conditions of anaesthesia. It is also possible that medications or sensory input to increase arousal could enhance oral bolus perception when it is reduced. Future studies should explore these potential correlations between the perception of oral stimuli and related functional swallowing physiology in both the elderly and dysphagic populations and determine whether sensory enhancements or arousal-related treatments could improve performance and swallowing safety.

The current data add to our understanding of perceptual changes with age and suggest future research with ageing normal and dysphagic individuals. More specific data regarding cortical activation patterns under various conditions may highlight future treatments using technologies such as transcranial direct current stimulation or guide future treatment studies with a variety of sensory alterations designed to elicit the necessary cortical activation for successful deglutition.

Limitations of this study include a relatively small sample size and broad age group definitions. Future studies should narrow the definitions of age groups to include young (20–40), middle age (40–60), older (60–80) and older plus (80 +) to further parse how sensation and sensory perception can change over the lifespan.

Ethical approval

The local institutional review board approved the study, and all participants signed an approved consent form.

Disclosures/Acknowledgments

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Conflict of interest

Authors have no conflict of interest to report.

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